AD 732373

NOLTR 71-107

CONSTANT CURRENT INITIATION OF PRIMARY EXPLOSIVES

By
Howard S. Leopold

17 SEPTEMBER 1971

NOL

NAVAL ORDNANCE LABORATORY, WHITE OAK, SILVER SPRING, MARYLAND

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Ordnance Laboratory White Oak, Silver Spring, Maryland 20910	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

CONSTANT CURRENT INITIATION OF PRIMARY EXPLOSIVES

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

Howard S. Leopold

6. REPORT DATE 17 September 1971	7a. TOTAL NO. OF PAGES iv +22	7b. NO. OF REFS 11
8a. CONTRACT OR GRANT NO. b. PROJECT NO. ORD-332-001/092-1/UF17-354-314 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NOLTR 71-107 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Ordnance Systems Command

13. ABSTRACT

The constant current firing of diazodinitrophenol/potassium chlorate, lead styphnate, and lead azide was investigated. The temperature excursion of the bridgewire during constant current heating can be influenced by the density of the explosive, explosive phase changes, and heat generated by the explosive. Voltage inflection techniques indicate that diazodinitrophenol undergoes a phase change and is in a molten state at the time of ignition. The contant current time of initiation (and energy requirement for initiation) increase with loading density for normal lead styphnate and lead azide.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Hot Wire Ignition Initiation Normal Lead Styphnate Lead Azide Diazodinitrophenol						

CONSTANT CURRENT INITIATION OF PRIMARY EXPLOSIVES

Prepared by:

Howard S. Leopold

ABSTRACT: The constant current firing of diazodinitrophenol/potassium chlorate, lead styphnate, and lead azide was investigated. The temperature excursion of the bridgewire during constant current heating can be influenced by the density of the explosive, explosive phase changes, and heat generated by the explosive. Voltage inflection techniques indicate that diazodinitrophenol undergoes a phase change and is in a molten state at the time of ignition. The constant current time of initiation (and energy requirement for initiation) increase with loading density for normal lead styphnate and lead azide.

EXPLOSION DYNAMICS DIVISION
EXPLOSIONS RESEARCH DEPARTMENT
NAVAL ORDNANCE LABORATORY
WHITE OAK, SILVER SPRING, MARYLAND

NOLTR 71-107 17 September 1971

CONSTANT CURRENT INITIATION OF PRIMARY EXPLOSIVES

This report describes the results of an investigation on the constant current initiation of a diazodinitrophenol/potassium chlorate mixture, normal lead styphnate, and lead azide. The work was performed under Task ORD 332-001/092 1/UF17-354-314.

The results should be of interest to persons engaged in initiation research and in the design of electric initiators and their power supplies.

The identification of commercial materials implies no criticism or endorsement of these products by the Naval Ordnance Laboratory.

ROBERT ENNIS
Captain, USN
Commander

C J Aronson

C. J. ARONSON
By direction

CONTENTS

TABLES

ILLUSTRATIONS

CONTENTS (Continued)

ILLUSTRATIONS

CONSTANT CURRENT INITIATION OF PRIMARY EXPLOSIVES

INTRODUCTION

1. The effective utilization of explosives and explosive trains requires a thorough understanding of the initiation process and the growth of explosion. Many factors affecting the initiation of explosives in initial explosive components have still not been explained. Further studies of these factors, both chemical and physical, is needed in order to build safe, reliable, and effective fuze trains.

2. Electro-explosive devices are frequently evaluated by the use of constant current firing pulses since the dynamic bridgewire resistance change can be measured by monitoring the voltage (V) across the bridgewire. Since the current (I) is constant, the resistance (R) can be calculated from $\frac{V}{I}$.

3. During the constant current pulse firing of the Squib Mk 1 Mod 0 for the HERO program,[1]* it was noticed that the average ignition time of the bridgewire explosive, diazodinitrophenol/potassium chlorate (DDNP/$KClO_3$), as indicated by the voltage inflection technique,[2,3] was significantly larger than the 50%-pulse-time obtained by Bruceton testing. See Table 1. Variation of the constant current test levels from 0.5 to 8 amperes produced time differences ranging from 170 to 15usec respectively between the required pulse length for 50% functioning as indicated by Bruceton testing and the average time of ignition.

4. The purpose of this investigation was to examine the constant current initiation of primary explosives with the intent of providing an explanation for the delayed ignition phenomenon. The more commonly used initiating explosives-normal lead styphnate and lead azide-were also investigated in addition to the DDNP/$KClO_3$ mixture.

EXPERIMENTAL

5. The three test explosives

a. Diazodinitrophenol/potassium chlorate (DDNP/$KClO_3$) (75/25)

b. Milled normal lead styphnate (NLS)

c. Milled dextrinated lead azide

were loaded on bridged phenolic initiator plugs for evaluation. All charges were dry pressed on the bridgewire, the DDNP/$KClO_3$ charge differing from the actual Squib Mk 1 Mod 0 application in that nitro-starch was not added and the mixture was not "buttered" on the bridgewire.

*References are on page 8.

6. A constant current pulse of a duration longer than necessary for firing was used to determine the average time of initiation for each of the three test explosives. A Bruceton test, with the pulse duration as the variable, was subsequently run using the same current level. A comparison was then made of the average firing time and the pulse length required for 50% functioning as determined by Bruceton testing.[4] The "voltage inflection technique",[2,3] and the "light pipe technique"[5] were both employed to determine the time of initiation.

EXPERIMENTAL APPARATUS

7. Firing Circuit. Two firing circuits were used during the investigation. A d.c. power supply in conjunction with a mercury wetted millisecond switch was used to produce the longer constant current pulses (>10 milliseconds).[6] Pulses shorter than 10 milliseconds were produced by a transistor current switch.[7] Constant current values of 0.30 to 0.70 ampere were used, these values give initiation times within the control periods of the switches and yet do not burn out the bridgewire during the time region of interest.

8. Initiator Plug. A specially modified initiator plug was used for loading the explosive on the bridgewire. A hole was drilled axially through the initiator plug between the two contact pins and a light pipe potted in this hole so that radiation from the initial reaction of the explosive could be detected and transmitted to a photodetector tube. See Figure 1. The plug was bridged with 1-mil dia. nichrome wire having an effective length of 0".050 after soldering to the contact pins. The bridgewire had a resistance range of 2.5-4.0 ohms. An equivalent resistor (within 0.25 ohm of the bridgewire to be tested) was first substituted in the firing circuit before each shot to regulate to the desired current value.

9. Recorder. A Tektronix 555 Dual-beam oscilloscope with two fast rise Type K preamplifiers was used to observe the voltage across the wire and the photodetector tube signal. The voltage inflection technique requires no special equipment other than a means of monitoring the voltage (IR drop) across the bridgewire during the current pulse. It is difficult to make measurements of the voltage change across the wire when the entire signal amplitude is observed, since for the experimental conditions there is only a 4-8% increase in resistance before initiation occurs. In order to amplify the voltage change in the signal by using a high oscilloscope sensitivity, the beam spot must be set well below the viewing screen. Then, only the signal portion of interest is observed. If the oscilloscope vertical position dial does not provide sufficient latitude, a variable bucking voltage can be employed to lower the beamspot.

RESULTS

10. DDNP/$KClO_3$. A constant current pulse of 0.30-ampere amplitude was used to fire ten initiator plugs loaded at 10,000 psi with DDNP/$KClO_3$. The pulse had a longer duration than necessary for firing

and the average time of ignition was found to be 10.94 milliseconds.* A 25-shot Bruceton test, using the same experimental conditions, gave a pulse time of 10.24 milliseconds for 50% functioning. This was 6.4% less than the average observed time, confirming the Squib MK1 Mod0 observations.

11. The same tests were repeated using a 0.70-ampere pulse. The average time of ignition was 1.20 milliseconds, while the Bruceton test gave a 50% functioning time of 1.05 milliseconds, a 12.5% lower time requirement.

12. Examination of the voltage drop (IR) across the bridgewire revealed that though irregularities are common, a definite change in slope can be detected with the 0.30-ampere input level whether or not the mixture is ignited. See Figure 2. The average temperature of the bridgewire at the time of the slope change was determined to be 153°C. Since the handbook values of the melting points are 157°C for DDNP and 368°C for $KClO_3$, this result indicates that the slope change is due to melting of the DDNP. It can be assumed that the DDNP is in a molten state at the time of ignition. It also indicates that the explosive adjacent to the bridgewire is in close temperature equilibrium with the bridgewire for the 0.30-ampere input level. The slope change is barely discernible at the 0.70-ampere level and occurs at temperatures variably higher than 157°C indicating, as expected, a greater temperature lag between the bridgewire and the explosive with faster electrical inputs.

13. Firings were not conducted with the mixture loaded at pressures other than 10,000 psi since the mixture is usually employed as a buttered charge. The use of DDNP is declining due to its relatively poorer thermal stability in comparison with other initiating explosives.

14. The two detection techniques employed (voltage inflection and light pipe) complement each other in the examination of constant current initiation. When ignition takes place during the current pulse, both methods confirm each other. See Figure 2. The voltage inflection technique has the added advantage in that resistance changes such as the one caused by the DDNP phase change can also be detected. The light pipe technique advantage is that it can detect ignition after cessation of the current pulse. During the Bruceton testing, eight ignitions were detected by the light pipe technique after cessation of the current flow. See Figure 3.

15. NLS - A constant current pulse of 0.30-ampere amplitude was used to fire ten initiator plugs loaded with milled NLS at 10,000 psi. When using a pulse duration longer than necessary, the average time of ignition was found to be 51.05 milliseconds. A 40-shot Bruceton test, using the same experimental conditions, gave a 50% pulse time for firing of 48.73 milliseconds, 4.5% less than the average observed time. See Tables 2 and 3.

*Fifty percent of any similar items tested would be expected to function in times shorter than 10.94 milliseconds and 50% would be expected to function at times greater than 10.94 milliseconds.

16. Using a pulse of 0.30 ampere for a period longer than necessary, the average ignition times were determined for NLS at 2,500 and 60,000 psi loading pressures. Ten shots were fired at each pressure and the results are shown in Figure 4 along with the 10,000 psi results. It can be seen that the time to ignition and the energy required for ignition increase with loading pressure.

17. Comparisons of the average time of ignition with the Bruceton test results were also made at two higher current levels with the NLS loaded at 10,000 psi. At a 0.375-ampere level, the average time of ignition was 11.77 milliseconds, while the Bruceton test gave a 50%-pulse time of 11.43 milliseconds, 2.9% less than the observed average time. At a 0.70-ampere level, the average time of ignition was 2.00 milliseconds, while the Bruceton test results gave a 50%-pulse time of 1.88 milliseconds, 6% less than the observed average time.

18. No ignitions of NLS were observed after the cessation of the current pulse in the Bruceton tests. All three Bruceton tests, however, indicated a shorter pulse length was necessary than the observed average time of ignition. At the lower current inputs, especially the 0.30-ampere level, a definite increase in resistance can sometimes be seen over that expected from the electrical heating of the bridgewire. See Figure 5. This indicates an exothermic decomposition of the explosive before ignition is observed. The bridgewire for a short period is being heated by both electrical energy and the heat released from the NLS.

19. Lead Azide - An attempt was made to fire ten initiator plugs loaded with milled dextrinated lead azide at 10,000 psi using a constant current pulse of 0.30-ampere amplitude. Consistent firings could not be obtained at this current level and the pulse amplitude was increased to 0.375 ampere. When using a pulse of 0.375 ampere for a period longer than necessary the average time of initiation was found to be 22.18 milliseconds. A 25-shot Bruceton test run under the same conditions with the duration of the pulse as the variable gave a 50% initiation time of 21.62 milliseconds, 2.5% less than the average observed time.

20. The average initiation times were determined for lead azide at 2,500 and 60,000 psi loading pressures using a 0.375-ampere pulse for a period longer than necessary. Ten shots were fired at each loading pressure and the results are shown in Figure 6 along with the 10,000 psi loading pressure results. The time to initiation and the energy requirement for initiation increase with loading pressure.

21. There is also an indication of exothermic decomposition of lead azide just before initiation as evidenced by the increase in bridgewire resistance over that expected from electrical heating. See Figure 5. Several irregularities are observed in the resistance rise of the bridgewire, similar to those seen with the other explosives.

DISCUSSION

22. The six comparisons made in this investigation of the average time of initiation with the 50% required pulse duration obtained from Bruceton testing all show that a shorter duratic constant current pulse is necessary than the time of initiation. See Table 4. These comparisons confirm the Ayres and Goode observations and also show that the phenomenon is not limited to a DDNP/$KClO_3$ mixture.

23. It is known that a constant current pulse initially effects a rapid temperature rise in the bridge which then asymptotically approaches a temperature limit. The type of temperature rise has been predicted by various mathematical models[8,9] and verified experimentally. See Figure 7.

24. If the constant current pulse heating of the bridgewire is observed with an infrared sensitive photodetector tube, a trace is obtained as shown in Figure 8. The initial temperature rise of the bridgewire is not observed since the tube is not sensitive enough to detect wavelengths longer than 1.1 microns. The infrared signal shows the bridgewire temperature is still increasing slightly for the pulse lengths employed. One can also observe that the bridgewire temperature does not abruptly drop with cessation of the electrical pulse, but undergoes an exponential cooling. In other words, the heat pulse to the explosive can continue for a short period after cessation of the electrical pulse and effect initiation under certain conditions.

25. Ignitions were observed after cessation of the current pulse in the tests with the DDNP/$KClO_3$ mixture. The delayed ignition occurred within time limits that strongly indicate the ignition took place during the cooling period of the bridgewire. In this case, it is readily apparent why the average pulse length is shorter than the observed average ignition time.

26. In the experiments with NLS and PbN_6 where no initiations were observed after cessation of the electrical pulse, the Bruceton average pulse time was still less than the average initiation time indicating the involvement of other factors. Heat generation from both of these explosives was observed just prior to initiation. See Figure 5.

27. One possible explanation of why a shorter pulse length requirement than the average time of initiation is observed is that when decomposition is observed prior to initiation, the decomposition can continue and proceed to initiation even if the current pulse was terminated during the decomposition period. If this were true, initiations would be expected to occur after the end of the current pulse. Initiations were not observed after the end of the current pulse for NLS and PbN_6, thereby eliminating this explanation for the time differential for these two explosives.

28. Another possible explanation for the shorter pulse requirement is the possibility that the distribution of firing times is skewed to the

longer times. This might occur if the resistance values were skewed to the low side or if the heat loss factor was skewed to the high side. Either one of these effects would result in moving the expected time-temperature profile, as shown in Figure 7, toward the long time for reaching the firing temperature. With a distribution positively skewed to the longer times the median will be less than the average. Since Bruceton testing is concentrated about the median, the pulse duration time would be less than the average initiation time. To determine if a skewed distribution is obtained with the constant current pulse employed, sixty-eight shots were run with NLS. A 0.375-ampere pulse with a duration longer than necessary was used for firing and the times of ignition noted. The tabulated dispersion of the firing times is shown in Figure 9. There is a well-defined mode and Pearson's measure of skewness,

$$\text{Skewness} = \frac{\text{Arithmetic mean} - \text{Mode}}{\text{Standard Deviation}},$$

was used to examine the data. A positive skewness number of 0.32 was obtained, indicating a slight skewness. The resistance value distribution of the sixty-eight items used in the test actually had a very slight positive skewness (skewness number = 0.12) directly opposite to what would be expected to give firing time skewed to the longer times. This eliminated the resistance value distribution as the cause of the firing time skewness, leaving the heat loss factor as the most likely origin of the skewness.

29. The effects of loading pressure on initiation were examined for NLS and PbN_6. For the amplitude of the constant current used in these experiments the time of ignition and the energy requirement of NLS increased with loading pressure. This observation was previously reported.[10] Also for the experimental conditions employed, the time of initiation and energy requirement of PbN_6 increased with loading pressure. This result is of interest since azides were observed to become more sensitive with increasing density when initiated by a capacitor discharge. It appears that the radial heat loss characteristics during non-adiabatic constant current initiation far outweigh the physico-chemical decomposition properties previously postulated to give greater sensitivity to higher density azides.[11]

30. The resistance excursion of the bridgewire during constant current heating is strongly dependent upon the type and composition of the explosive surrounding the bridgewire. Nichrome wire in the hard condition instead of the annealed condition is frequently used as the bridge material because of its greater tensile strength and smaller elongation factor. The lower the explosive density, the greater the freedom of movement allowed the bridgewire during the constant current heating cycle. The ability of the wire to move and thus relieve stress during heating may account for the larger number of resistance irregularities seen at the lower densities. As shown in the experimental results, phase changes in the explosive and heat generated by the explosive also affect the resistance excursion, with the effects more discernible at the lower current input levels.

31. There is a strong possibility that the DDNP/$KClO_3$ mixture also undergoes an exothermic decomposition before ignition similar to that observed with NLS and PbN_6. This is not observed experimentally on the oscillograms since any heat release would be masked by the heat absorption during the DDNP phase change.

CONCLUSIONS

32. A comparison of the average time of initiation with the 50% constant current pulse length obtained from Bruceton testing shows that the pulse length necessary is shorter than the time of initiation. One possible cause for the difference is that the heat pulse from the bridgewire has a longer duration than the current pulse due to the time required for bridgewire cooling. Another possible cause is that the temperature excursion of the bridgewire during a non-adiabatic constant current pulse gives a skewed distribution, separating the average time from the median time.

33. The resistance excursion of the bridgewire during non-adiabatic constant current pulsing can vary quite markedly from that predicted by mathematical models which do not include explosive phase changes or heat produced by chemical reaction. These effects can be minimized by increasing the pulse amplitude.

34. The non-adiabatic constant current initiation time and energy requirement of both NLS and PbN_6 can be increased by increasing the loading density.

REFERENCES

1. Ayres, J. N., and Goode, C. W., Unpublished Work

2. Korty, V. M., "A Differential Resistance Method for Measuring Ignition Times and Threshold Firing Energies of Electric Primers," NOLM 8636, July 1946

3. Mallory, H. D. and Goss, F. A., "A New Method for the Measurement of Initiation Times in Hot Wire Ignitions" in Proceedings of the Gilbert B. L. Smith Memorial Conference on Explosive Sensitivity, NAVORD Report 5746, June 1958, Unclassified

4. "Statistical Analysis for a New Procedure in Sensitivity Experiments," AMP Report No. 101.1R SRG-P, No. 40, 1944; a report submitted by the Statistical Research Group, Princeton University

5. Leopold, H. S., "A New Technique for Detecting the Initial Reaction of Primary Explosives Initiated by Hot Wire," NOLTR 69-148, Nov 1969

6. Rosenthal, L. A., "Millisecond Switch for Electroexplosive Testing," IEEE Transactions on Instrumentation and Measurement, Vol. 1M-18, No. 1, March 1969

7. Rosenthal, L., "Generator Delivers Constant Current or Voltage Pulses," Electronics, Sept 1960

8. Rosenthal, L., "Electro-Thermal Equations for Electro-Explosive Devices," NAVORD Report 6684, Aug 1959

9. Evans, J., "Explosive Initiation Evaluation," Instruments & Control Systems, Oct 1969

10. Leopold, H., "Comparison of Constant Current and Capacitor Discharge Ignition of Normal Lead Styphnate," NOLTR 70-236, Mar 1971

11. Leopold, H., "Effect of Reduced Ambient Pressure on the Hot Wire Sensitivity of Primary Explosive, Metal-Oxidant Mixtures, and Black Powder, NOLTR 68-199, Jan 1969

Table 1 Constant Current Pulse Firing of MK 1 Squibs*

Current (amperes)	Average Pulse Length[1] (microseconds)	Average Ignition Time[2] (microseconds)	Induction Time (microseconds)	Induction Time as a Percent of Avg Ignition Time
0.5	9,480	9,650	170	1.76
1.0	1,280	1,400	120	8.57
2.0	235	354	119	33.6
4.0	65	104	39	37.5
6.0	27	60	33	55.0
8.0	17	32	15	46.9

*Unpublished data from J. N. Ayres and C. W. Goode

[1] From Bruceton Testing (arithmetic steps)

[2] From Voltage Inflection Technique (explosive on bridgewire)

Table 2 Bruceton Test of Normal Lead Styphnate

EXPLOSIVES SENSITIVITY TEST
PRNC-NOL-8010 2 (11-62)

	—
Milled Normal Lead Styphnate	—
0.30 ampere	5.2 milliseconds
0"001 nichrome 2.5-4.0 ohms	Yes
Calculated 50% pulse time - 48.73	H. L.
40	—
Oscillogram taken of each shot	

millisec																																								
62.0																																								
56.8		X		X										X																						X				
51.6	O		O		X		X		X		X		O		X				X		X		X		X		X								O		X			
46.4						O		O		O		O				X		O		O		O		O		O		X		X		X		O				X		O
41.2																	O												O		O		O						O	
36.0																																								

Table 3 Analysis of Bruceton Shots

Shot No.	Bridgewire Resistance (R) (ohms)	Pulse Length (millisec)	Result	Firing Time (millisec)	$\frac{\Delta R}{R}$* (%)	Bridgewire Temperature* (°C)
1	3.0	51.6	NF	——	5.3	371
2	3.1	56.8	Fire	42.5	4.8	338
3	3.1	51.6	NF	——	5.5	388
4	2.7	56.8	Fire	56.1	5.6	396
5	3.2	51.6	Fire	49.2	5.7	401
6	2.7	46.4	NF	——	5.4	382
7	2.9	51.6	Fire	46.5	5.8	405
8	3.1	46.4	NF	——	4.3	307
9	3.1	51.6	Fire	50.8	5.7	400
10	3.2	46.4	NF	——	4.5	317
11	2.9	51.6	Fire	46.5	5.5	388
12	3.2	46.4	NF	——	4.0	289
13	3.0	51.6	NF	——	7.9	553
14	3.3	56.8	Fire	45.8	7.1	491
15	3.0	51.6	Fire	44.7	5.8	407
16	2.8	46.4	Fire	43.5	6.1	430
17	[illegible].1	41.2	NF	——	4.8	339
18	3.0	46.4	NF	——	5.[illegible]	359
19	2.8	51.6	Fire	43.5	5.9	414
20	2.9	46.4	NF	——	4.0	287
21	3.0	51.6	Fire	48.8	5.6	390
22	3.0	46.4	NF	——	5.7	401
23	3.0	51.6	Fire	30.0	4.6	324

*At time of ignition or end of pulse

Table 3 Analysis of Bruceton Shots (Continued)

Shot No.	Bridgewire Resistance (R) (ohms)	Pulse Length (millisec)	Result	Firing Time (millisec)	$\frac{\Delta R}{R}$* (%)	Bridgewire Temperature* ($^{\circ}$C)
24	3.1	46.4	NF	——	4.5	319
25	3.2	51.6	Fire	48.4	5.3	369
26	3.0	46.4	NF	——	6.5	456
27	3.1	51.6	Fire	48.0	5.5	384
28	3.1	46.4	Fire	42.9	5.2	366
29	3.1	41.2	NF	——	4.8	339
30	3.0	46.4	Fire	44.4	4.5	313
31	3.0	41.2	NF	——	4.7	333
32	2.8	46.4	Fire	45.4	5.4	379
33	3.0	41.2	NF	——	5.9	413
34	3.0	46.4	NF	——	5.0	355
35	3.2	51.6	NF	——	3.5	254
36	3.1	56.8	Fire	52.2	5.1	360
37	3.1	51.6	Fire	50.5	5.2	364
38	3.0	46.4	Fire	44.5	5.6	393
39	2.8	41.2	NF	——	4.4	314
40	3.2	46.4	NF	——	3.7	266

Table 4 Constant Current Pulse Firing of Primary Explosives

Explosives	Current (ampere)	Average Pulse Length[1] (milliseconds)	Average Ignition Time[2] (milliseconds)
DDNP/$KClO_3$	0.30	10.24	10.94
DDNP/$KClO_3$	0.70	1.05	1.20
NLS	0.30	48.73	51.05
NLS	0.375	11.43	11.77
NLS	0.70	1.88	2.00
PbN_6	0.375	21.62	22.20

[1] From Bruceton Testing (arithmetic steps)

[2] From Voltage Inflection and Light Pipe Techniques

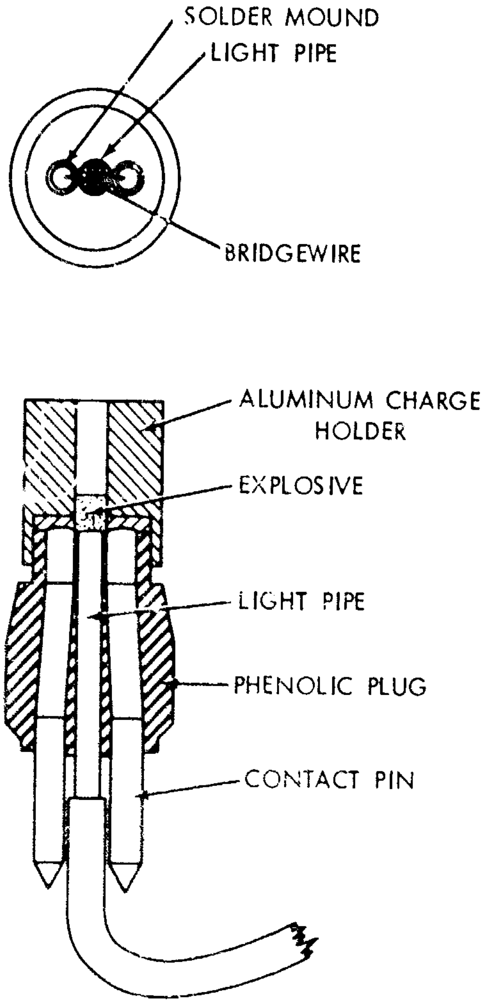
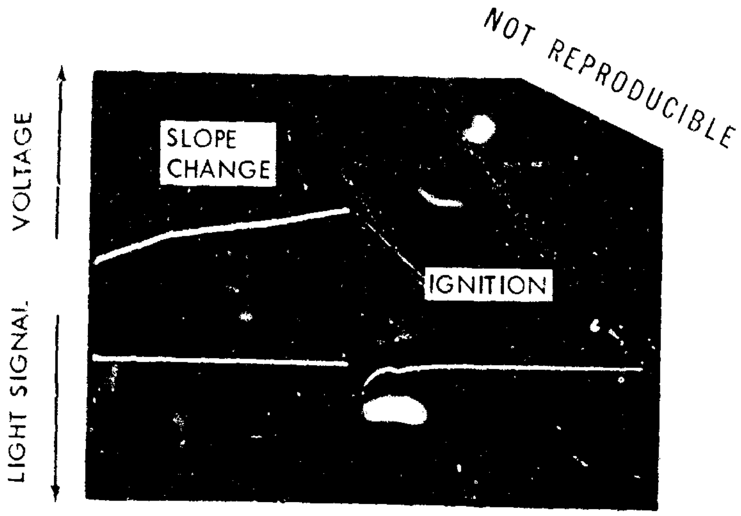
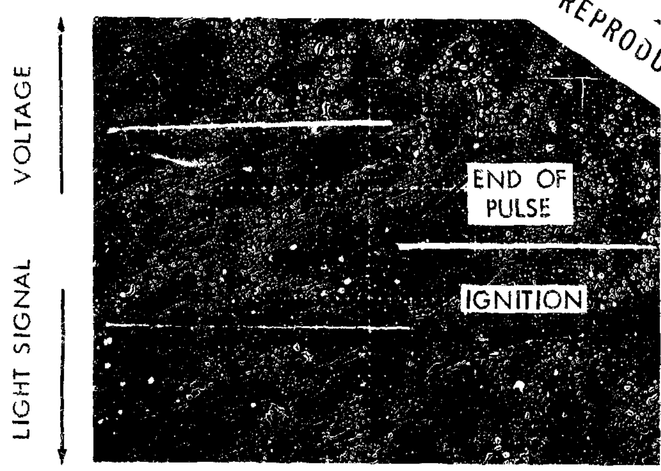


FIG. 1 MODIFIED INITIATOR PLUG



SWEEP SPEED = 2 MILLISECONDS/DIV
CONSTANT CURRENT = 0.3 AMPERE

FIG. 2 OSCILLOGRAM SHOWING SLOPE CHANGE AND IGNITION OF $DDNP/KClO_3$ MIXTURE



SWEEP SPEED = 0.2 MILLISECONDS/DIV
CONSTANT CURRENT = 0.7 AMPERE

FIG. 3 OSCILLOGRAM SHOWING IGNITION OF DDNP/$KClO_3$ MIXTURE AFTER CESSATION OF CURRENT PULSE

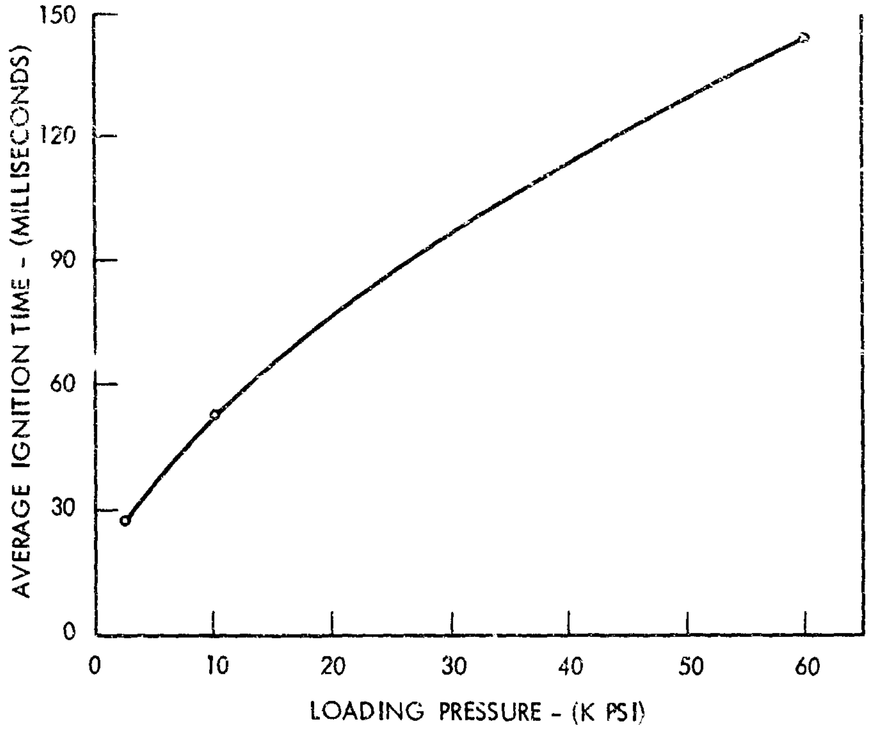
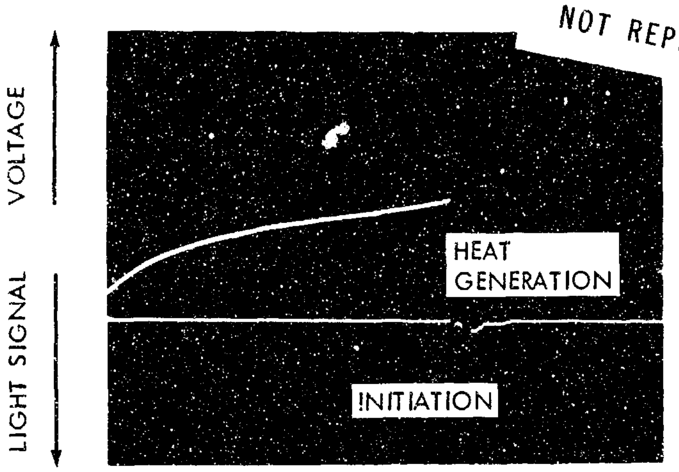
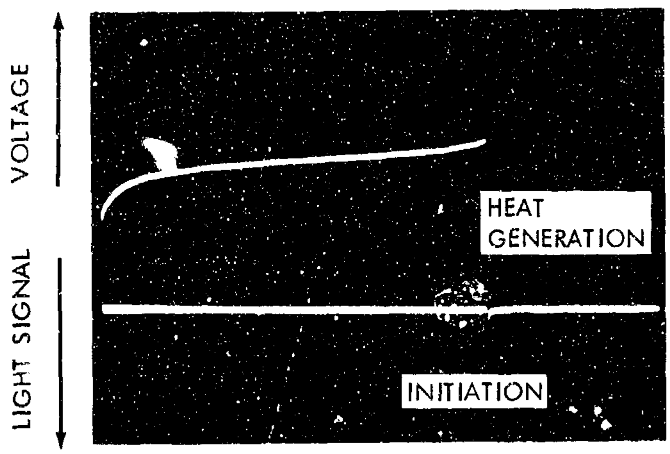


FIG. 4 EFFECT OF LOADING PRESSURE ON CONSTANT CURRENT (0.3 AMPERE) IGNITION TIME OF NORMAL LEAD STYPHNATE



NORMAL LEAD STYPHNATE
SWEEP SPEED = 2 MILLISECONDS/DIV



LEAD AZIDE
SWEEP SPEED = 10 MILLISECONDS/DIV

FIG. 5 OSCILLOGRAMS SHOWING HEAT GENERATION PRIOR TO INITIATION

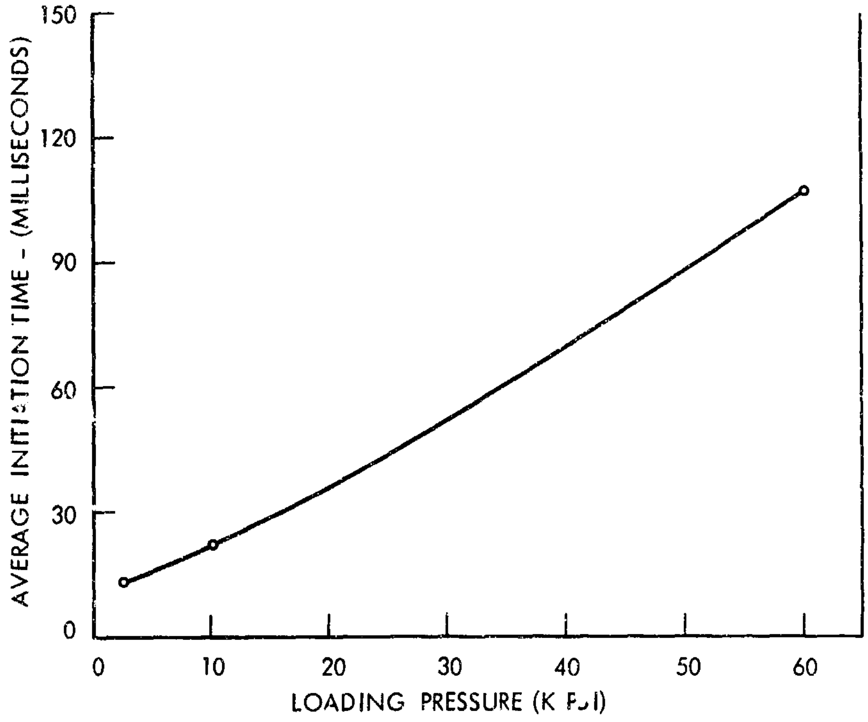


FIG. 6 EFFECT OF LOADING PRESSURE ON CONSTANT CURRENT (0.375 AMPERE) INITIATION OF LEAD AZIDE

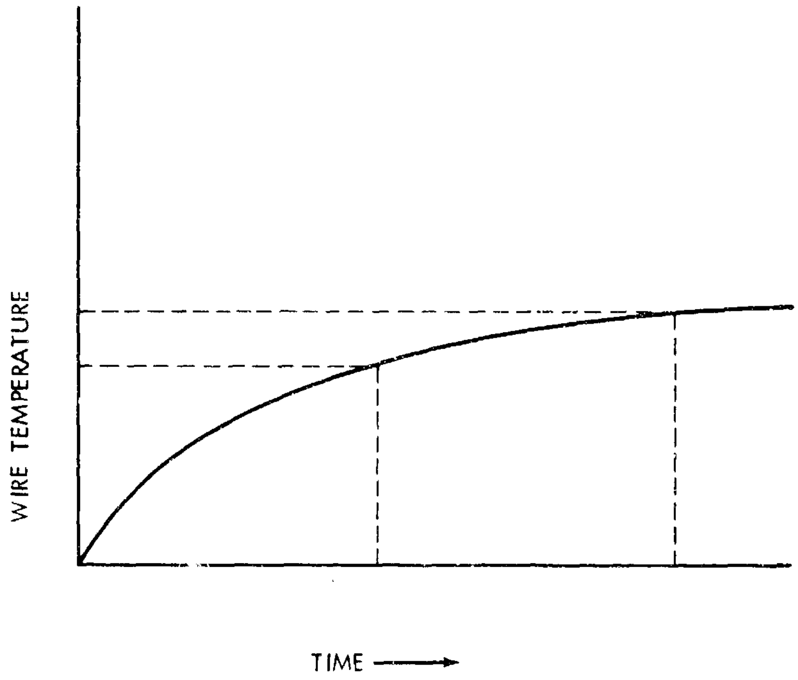
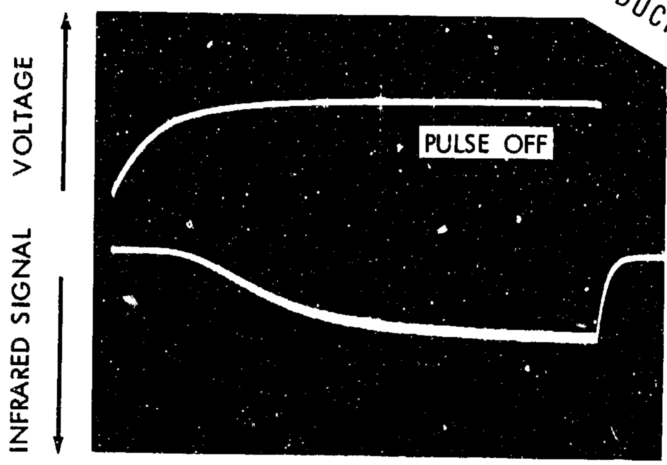


FIG. 7 INCREASE IN BRIDGEWIRE TEMPERATURE VS. TIME



SWEEP SPEED = 10 MILLISECONDS/DIV

FIG. 8 OSCILLOGRAM SHOWING CONSTANT CURRENT HEATING OF BARE WIRE

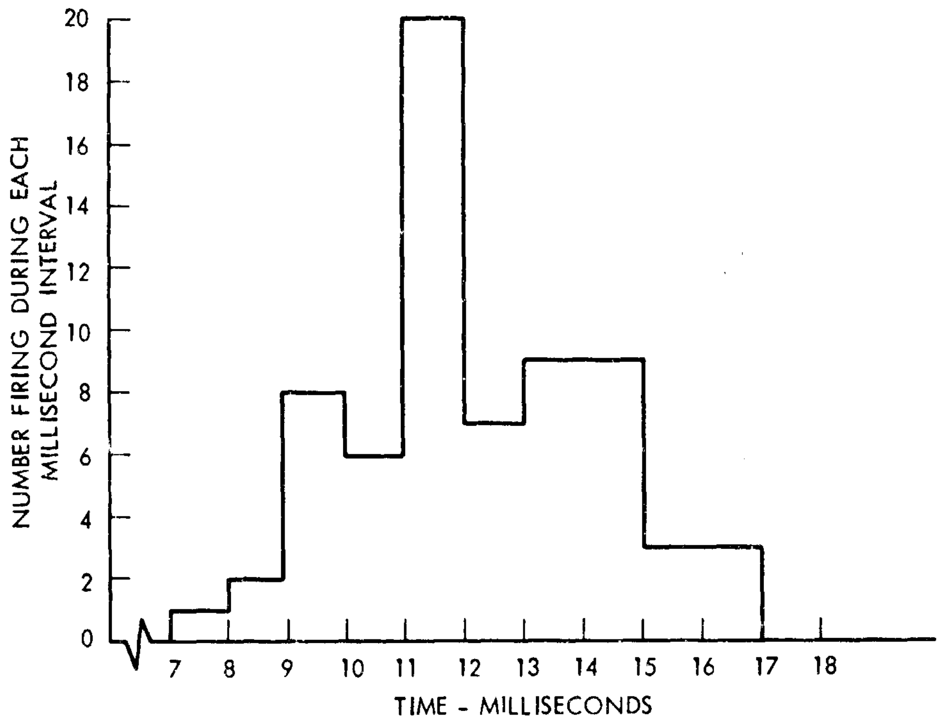


FIG. 9 EXAMINATION OF FIRING TIME DISTRIBUTION OF NORMAL LEAD STYPHNATE WITH 0.375 AMPERE CONSTANT CURRENT PULSE